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Analysis of China's energy consumption and economic growth based on the Tapio decoupling model

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At present, driven by the urgent demands of the "dual carbon" goals and industrial transformation and upgrading, the underlying logic of the relationship between China's energy consumption and economic development has undergone changes. This study employs the Tapio decoupling model to analyze the decoupling relationship between China's energy consumption and economic growth during the period from 2006 to 2024, covering the 11th to the 14th Five-Year Plans, and provides prospects for the 15th Five-Year Plan. The results show that: (1) The decoupling state between China's total energy consumption and economic growth has shifted from weak decoupling to expansive coupling; however, with the realization of the "dual carbon" goals, the relationship between China's energy consumption and economic growth is likely to return to the track of weak decoupling during the 15th Five-Year Plan period. (2) Significant differences exist in the decoupling indices among fossil energy sources with different carbon emission levels. Coal and oil generally exhibit a state of weak decoupling, while natural gas has long been in a state of expansive negative decoupling. During the 15th Five-Year Plan period, coal and oil may shift toward strong decoupling, However, natural gas may achieve weak decoupling, as economic growth is becoming increasingly dependent on it. (3) Economic growth shows a high degree of dependence on non-fossil energy, which has long been in a state of expansive negative decoupling, and this state is expected to persist during the 15th Five-Year Plan period. This study helps to explore the internal linkage between energy consumption and economic development, Explore the intrinsic relationship between energy consumption and economic development, along with the underlying reasons for their decoupling state, thus providing references for China's energy policy optimization, the advancement of the "dual carbon" goals, and industrial transformation.

KEYWORDS

Tapio decoupling model, energy consumption, economic growth, decoupling states, sustainability

1 Introduction

Energy is a crucial substance in modern economic society. It serves as the "lifeblood" of the industrial economy and is closely linked to our daily lives. As a factor of production involved in economic activities, energy is a key driver of the development of modern society and economy (Zhang et al., 2018; Cox, 2018). Humanity has experienced three energy revolutions, centered on firewood, coal, and oil, respectively. Each of these revolutions has boosted the development of social productive forces and triggered transformations in production technologies. Therefore, energy and the economy not only promote each other's development but also constrain one another, with a causal relationship existing between them.

Economic development requires energy consumption, while economic growth, in turn, provides the technological and material conditions for energy exploration and utilization. However, the fossil energy shortage caused by economic growth has made energy security a global focus of attention (Wei et al., 2018). Simultaneously,climate governance has become an increasingly contested and politically charged domain (Yalaz1 et al., 2025; Victor-Gallardo et al., 2024).

Since the launch of the reform and opening-up policy, China's total energy consumption has exhibited an annual increase in parallel with its rapid economic development (Qian et al., 2017). The energy sector is the largest contributor to greenhouse gas emissions (Jian et al., 2025). Nevertheless, China's energy consumption pattern has shifted from "extensive growth" to "improving quality and efficiency," going through four distinct stages in total: The first stage is characterized by rapid energy consumption growth (2006–2010). In 2006, China's total energy consumption stood at 2.86 billion tons of standard coal, and by 2010, this figure had risen to 3.61 billion tons, representing an average annual growth rate of 6.8%. During this stage, economic growth relied heavily on heavy industries such as steel and cement, leading to massive fossil energy consumption, which posed a threat to the sustainability of China's economic development (Qian et al., 2018; Jian et al., 2021; Li et al., 2019). The second stage saw slowed energy consumption growth and structural adjustment (2011–2015). China's economic growth rate dropped from 10% in 2011 to 7% in 2015, while the average annual growth rate of energy consumption fell to 3.6%, and energy consumption per unit of GDP decreased by 18.4%. This was mainly driven by China's first-ever target of increasing the share of non-fossil energy to 11.4% (Jian et al., 2023b), as well as the phasing out of most high-energy-consuming capacities in 2015. Stricter environmental standards also forced the transformation of high-energy-consuming industries. The third stage marks an accelerated low-carbon transition (2016–2020). China's economic growth slowed significantly (Chen et al., 2025), while the pace of low-carbon transition accelerated. The average annual growth rate of energy consumption dropped to 2.5%, and energy intensity (energy consumption per unit of GDP) decreased by 15.3%. The fourth stage reflects rebounding energy consumption growth driven by economic recovery (since 2021). From 2021 to 2024, the average annual growth rate of China's total energy consumption reached 4.6%, significantly higher than the 2.5% recorded in 2016–2020. In particular, the growth rate reached 5.7% in 2023, the highest level in nearly a decade (see Figure 1). This change reflects the strong driving effect of economic recovery and industrial production expansion on energy demand, while also indicating the accelerated advancement of energy consumption structure transformation. Compared with 2016–2020, China witnessed rapid growth in demand for new energy from 2021 to 2024, with the share of non-fossil energy consumption continuing to rise. The newly installed capacity of wind power and photovoltaic power exceeded 100 million kilowatts for three consecutive years. In 2024, the share of non-fossil energy consumption reached 19.7%, and energy consumption per unit of GDP stood at 0.48 million tons of standard coal per 10,000 yuan, representing a cumulative decrease of 66% compared with 2005 (see Figure 2). Currently, China's energy transition is at a critical juncture (Liu et al., 2025). Jian et al. (2023a) access to sustainable and reliable electricity supply is critically important for economic growth.

According to existing research, the significant differences in the relationship between energy consumption and economic growth can be attributed to variations in research models, countries and regions, sample data, parameter estimation and hypothesis testing methods, as well as research periods. For instance, Kraft and Kraft (1978) studied the relationship between national income and energy consumption in the United States from 1947 to 1974, and the results revealed a unidirectional causal relationship between the two. Glasure and Lee (1998) investigated the relationship between energy consumption and income in South Korea and Singapore, but found no cointegration relationship between them. Paul and Bhattacharya (2004) identified a long-term equilibrium relationship between energy consumption and economic growth in India from 1950 to 1996. Lee (2005) found a bidirectional causal relationship among economy, capital and energy in 18 developing

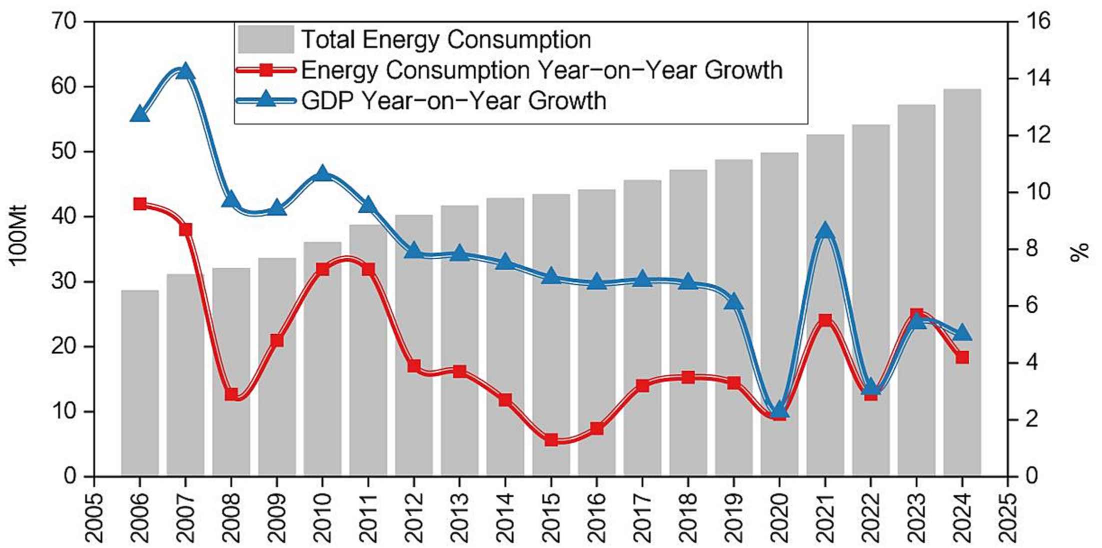

FIGURE 1
Changes in China's total energy consumption and its economic growth rate (2006–2024).

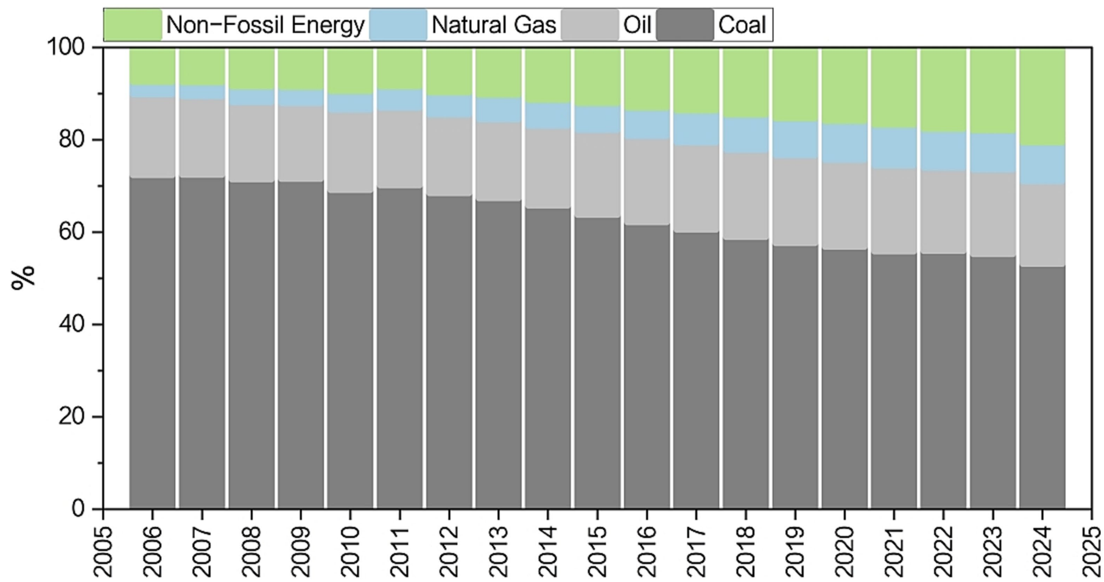

FIGURE 2
Changes in the proportion of China's primary energy consumption structure (2006–2024).

countries. Apergis and Payne (2010) reported a bidirectional causal relationship between coal consumption and economic growth in 15 emerging market countries from 1980 to 2006. Lin and Benjamin (2018) argued that bidirectional causal relationships existed between economic growth and energy consumption, as well as between economic growth and foreign direct investment (FDI) inflows in Mexico, Indonesia, Nigeria and Turkey; in addition, there was a unidirectional causal relationship from FDI to energy consumption. Eden and Hwang (1984) failed to find a causal relationship between national income and energy consumption through his research. Parrique et al. (2019) found that the possibility of achieving absolute decoupling between total energy consumption and economic growth in the future is relatively small. Lange et al. (2020) found that digitalization has not achieved energy conservation; on the contrary, it has resulted in higher energy consumption. If economic growth relies on a large number of digital services, energy demand may grow indefinitely.

The term "decoupling" originates from physics, referring to the separation of two interconnected motions. In the 1990s, the Organization for Economic Co-operation and Development (OECD) applied this concept to study the relationships between agricultural policies, trade, and production, and introduced it into the field of environmental economics (Sun and Li, 2011). The Organisation for Economic Co-operation and Development (OECD) first proposed the concept of "decoupling" at an economic level in its report "Indicators to Measure Decoupling of Environmental Pressure from Economic Growth," thus providing a theoretical framework for research on energy consumption and economic development. Since then, the "decoupling" theory has been applied in a wide range of research fields (OECD, 2002). For example, Chen et al. (2020) studied the decoupling relationship between global agricultural energy consumption and economic growth. Chen et al. (2017) and Sjöström and Östblom (2010), among others, investigated the decoupling relationship between economic growth and pollutants. Wang et al. (2018a) analyzed the decoupling relationship between urban economic growth and water use in China. Wang et al. (2019) examined the decoupling relationship between economic growth and energy consumption in China and India, finding that China as a whole has achieved decoupling, while India's decoupling performance is poor. Wu et al. (2018) studied the decoupling relationship between economic output and carbon emissions in China's construction industry, noting that the accuracy of the Tapio method for analyzing decoupling status is not restricted by the length of the research cycle. Wang et al. (2018b) compared the decoupling status between carbon emissions and economic growth in China and the United States from 2000 to 2014, finding that China was in a state of weak decoupling in most years, while the United States showed strong decoupling. Ma et al. (2016), among others, found that China's economic growth and household carbon dioxide emissions showed an expansive decoupling state, with shifts in energy consumption structure fluctuating between weak decoupling and strong decoupling states.

In recent years, the decoupling relationship between energy consumption and economic growth has gradually become a research hotspot worldwide. For example, Wei et al. (2020) found that the decoupling relationship between total energy consumption and economic growth in developed regions of China is often overestimated, whereas the decoupling status in most central and western regions lags behind. Kan et al. concluded that global total energy consumption and the economy showed a weak decoupling state in most years; There are significant differences in the degree of decoupling between various energy types and economic growth. While gradual decoupling is occurring from oil and coal, substantial consumption of natural gas and renewable energy remains necessary (Kan et al., 2019). Wang and Wang (2019) reported that in the United States, energy intensity, R&D intensity, R&D efficiency, and sectoral carbon intensity contribute to the decoupling between economic growth and carbon emissions, whereas investment intensity, population size, and sectoral energy structure do not. Román-Collado et al. (2018) examined the decoupling relationship between energy consumption and GDP in Colombia. Bai et al. (2016) found that in Liaoning Province, energy intensity contributes to the decoupling status between energy consumption and economic growth, while economic structure and investment do not. Scholars including Wang and Su (2020), Li et al. (2021), Gao et al. (2021), Wang et al. (2017), Feng et al. (2019), Meng et al. (2018), Li and Qin (2019), Yu et al. (2019), and Yang et al. (2018) have studied the decoupling relationship between economic growth and energy consumption or carbon emissions. Zhang et al. (2019) and Ge et al. (2017), among others, have investigated the decoupling relationship between electricity consumption and economic growth. Domestic scholars such as Lan (2020), Zhao and Pang (2021), Chen (2021), Pang et al. (2023), Chen and Zeng (2024), and Niu et al. (2024) have studied the decoupling status between energy consumption and economic growth in different regions of China.

Against the backdrop of the "dual carbon" goals and the pressing need for industrial transformation and upgrading (Bao et al., 2024; Shi et al., 2023), China is striving to adjust its energy structure and enhance energy efficiency (Gao et al., 2025), gradually reshaping the underlying logic of the relationship between energy consumption and economic development. Between 2006 and 2024, China's energy consumption elasticity coefficient was approximately 0.65. Since 2020, with the significant growth in China's electricity consumption, the "decoupling" relationship between energy consumption and economic growth has undergone new changes. Using the Tapio decoupling index model, this paper takes 2006 as the base year, divides the period from 2006 to 2024 into four Five-year plan cycles, and calculates the decoupling indices during the four planning periods from the "11th Five-Year Plan" to the "14th Five-Year Plan." It investigates the decoupling relationship between China's energy consumption and economic growth in different planning periods, identifies the spatial–temporal evolution of the decoupling state between energy consumption and economic development, and explores the inherent connection between energy consumption and economic development as well as the in-depth reasons for their decoupling state.

2 Research methods and data sources

2.1 Tapio decoupling index and classification standards

In real-world economic development, a "recoupling" phenomenon may occur, which is the opposite of decoupling. Specifically, as the economy develops, energy consumption will automatically decrease after reaching a peak, thus presenting an inverted U-shaped relationship with economic growth. Subsequently, under certain circumstances, after energy consumption declines and achieves decoupling, it may rise again over time, thereby re-forming a recoupling phenomenon in which energy consumption and economic growth move in the same direction. This also implies that energy consumption and economic development may exhibit different decoupling states during different developmental periods.

Based on this definition, the relationship between the decoupling index (T) of energy consumption and GDP within a given period (t) can be derived. For details, see Equation 1:

$$T = \frac{\Delta E}{\Delta G} = \frac{\dfrac{E^t - E^0}{E^0}}{\dfrac{G^t - G^0}{G^0}} \tag{1}$$

Among them, T represents the decoupling index, △E denotes the energy consumption elasticity coefficient, and △G stands for the GDP growth elasticity coefficient. E^t and $E^{0, \text{ respectively,}}$ refer to the energy consumption in period t and the base period, while G^t and G^0 represent the real GDP in period t and the base period.

On this basis, Tapio (2005) further introduced the elasticity coefficient, that is, using the elastic decoupling index to describe eight possible decoupling states in practice. As shown in Table 1, a strong decoupling state is the most ideal scenario, characterized by sustained economic growth alongside a decrease in energy consumption. A weak decoupling state is relatively favorable, indicating improved energy efficiency where the growth rate of energy consumption is lower than that of the economy. A recessive decoupling state is unfavorable, meaning the decline rate of energy consumption is slower than the economic recession rate (i.e., energy consumption decreases at a slower pace than the economy shrinks). A growth coupling state occurs when both energy consumption and economic growth increase, with their growth rates being close to each other. In this case, there is no significant decoupling, and the economy's dependence on energy consumption does not decrease noticeably. A recessive coupling state refers to the simultaneous decrease of both energy consumption and the economy. A strong negative decoupling state is unfavorable, characterized by economic recession while energy consumption continues to grow. A weak negative decoupling state involves both economic recession and a decrease in energy consumption, with the decline rate of energy consumption being lower than the economic recession rate (i.e., energy consumption falls more slowly than the economy contracts). Finally, a growth negative decoupling state indicates that economic growth comes at the cost of

TABLE 1 Classification standards for elastic decoupling index.

Decoupling state		△E	△G	Elasticity index T(E，G)
Decoupling	Strong Decoupling (SD)	<0	>0	(T < 0)
	Weak Decoupling (WD)	>0	>0	(0 < T < 0.8)
	Recessive Decoupling (RD)	<0	<0	(T > 1.2)
Coupling	Expansionary Coupling (EC)	>0	>0	(0.8 < T < 1.2)
	Recessive Coupling (RC)	<0	<0	(0.8 < T < 1.2)
Negative Decoupling	Strong Negative Decoupling (SND)	>0	<0	(T < 0)
	Weak Negative Decoupling (WND)	<0	<0	(0 < T < 0.8)
	Expansionary Negative Decoupling (END)	>0	>0	(T > 1.2)

Source: Tapio (2005).

energy consumption, meaning the growth rate of energy consumption is higher than that of the economy.

2.2 Decoupling stability index

The decoupling index measures the decoupling relationship between the energy consumption and economic growth over a relatively long period, which may be either stable or fluctuating. However, analyzing stability sorely based on changes in the decoupling state within this period is insufficient. Therefore, it is necessary to analyze the decoupling stability of energy consumption in different periods. Qi et al. (2012), who studied the decoupling of urban industrial sectors, were the first to propose the need to assess the degree of decoupling stability. On this basis, Han et al. (2021), Pang et al. (2023), among others, carried out further studies on decoupling stability.

This paper also constructs a decoupling stability index and combines it with the decoupling state to analyze the relationship between energy consumption and economic growth. The decoupling stability index is a negative indicator. Since its value depends on the specific value of the decoupling index, there is no clearly defined range for the decoupling stability index. Specifically, the smaller the value, the more stable the decoupling state; conversely, the greater the fluctuation, the poorer the decoupling stability. For details, see Equation 2:

$$\partial = \sqrt{\frac{1}{N-1}\sum_{i-1}^{N}\left(\frac{T_{i+1}-T_i}{T_i}\right)^2} \tag{2}$$

Among them, N represents the total number of years under the decoupling study, i is a constant (i = 1,2,3,…, n), and Ti and Ti + 1, respectively, denote the decoupling index in the i-th period and the (i + 1)-th period.

2.3 Data sources

This study examines the decoupling between China's energy consumption and economic growth from 2006 to 2024, with 2006 as the base year for calculating the decoupling status. Based on the energy statistics table in the National Statistical Yearbook, energy is categorized into coal, oil, natural gas, primary electricity, and other energy sources. These energy types are further divided into traditional fossil energy and non-fossil energy: coal, oil, and natural gas belong to traditional fossil energy, while primary electricity and other energy sources are classified as non-fossil energy.

The period 2006–2024 is divided according to China's Five-Year Plans, namely the "11th Five-Year Plan" period (2006–2010), "12th Five-Year Plan" period (2011–2015), "13th Five-Year Plan" period (2016–2020), and "14th Five-Year Plan" period (2021–present). Due to incomplete statistical data for 2025, only data from 2021 to 2024 are used. The selected basic data are mainly sourced from the China Statistical Yearbook and China Energy Statistical Yearbook. To ensure data comparability and scientific validity, adjustments have been made to some basic data, as detailed below:

Source and conversion of GDP data: as indicated in Formula 1, the GDP growth elasticity coefficient is calculated using GDP values in period t and the base period. However, nominal GDP (GDP at current prices) does not exclude inflation factors, which may obscure the true effect of improved energy efficiency on GDP growth. Therefore, constant-price GDP is adopted in this study. By eliminating the impact of price changes, constant-price GDP can better reflect changes in physical volume, the actual changes in the outcomes of production activities, and the variation patterns across different years.

Source and conversion of energy consumption data: according to the formula, the energy consumption elasticity coefficient is calculated using energy consumption volumes in period t and the base period, and the formula essentially measures the growth rate of energy consumption. In contrast, the formula for calculating the energy consumption elasticity coefficient in the China Statistical Yearbook is the ratio of the annual growth rate of energy consumption to the annual growth rate of national economic development. The two methods differ in both concept and accounting scope, which requires emphasis here. A comparison shows that the calculation of the energy consumption elasticity coefficient in the China Statistical Yearbook reflects the relationship between changes in economic growth and changes in energy consumption, consistent with the indicator content reflected by the decoupling index. Therefore, data on total energy consumption and energy consumption by type from the China Statistical Yearbook are selected.

3 Empirical research results

3.1 Decoupling state between energy consumption and economic growth

The decoupling relationship between total energy consumption and economic growth is a core indicator for measuring a country's energy utilization efficiency, quality of economic growth, and sustainable development capacity. From 2006 to 2024, both China's total energy consumption and total economic output maintained sustained growth; however, the intensity of their correlation showed significant differences across periods, mainly manifesting in two states: weak decoupling and growth coupling (see Table 2). Overall, during China's "11th Five-Year Plan" to "12th Five-Year Plan" periods, the relationship between total energy consumption and economic development was generally in a state of weak decoupling, with the decoupling index gradually decreasing from 0.575 to 0.459. After entering the "13th Five-Year Plan" period, the index rose to 0.549, mainly due to the outbreak of the COVID-19 pandemic in 2020, which led to a sharp slowdown in economic growth and shifted the decoupling state between energy consumption and economic growth to growth coupling. If data from 2020 are excluded, the decoupling index would be 0.445. During the "14th Five-Year Plan" period, the decoupling state between energy consumption and economic growth shifted from weak decoupling to growth coupling. A detailed analysis is as below.

TABLE 2 Energy consumption, economic growth elasticity coefficient, and decoupling index in different periods.

Year	Periods	△E	△G	T
2006	"11th Five-Year Plan" Period (2006–2010)	0.096	0.127	0.756
2007		0.087	0.142	0.614
2008		0.029	0.097	0.304
2009		0.048	0.094	0.515
2010		0.073	0.106	0.688
Mean		0.067	0.113	0.575
2011	"12th Five-Year Plan" Period (2011–2015)	0.073	0.095	0.770
2012		0.039	0.079	0.494
2013		0.037	0.078	0.471
2014		0.027	0.075	0.365
2015		0.013	0.070	0.193
Mean		0.038	0.079	0.459
2016	"13th Five-Year Plan" Period (2016–2020)	0.017	0.068	0.250
2017		0.032	0.069	0.471
2018		0.035	0.068	0.519
2019		0.033	0.061	0.541
2020		0.022	0.023	0.966
Mean		0.028	0.058	0.549
2021	"14th Five-Year Plan" Period (2021–2024)	0.055	0.086	0.644
2022		0.029	0.031	0.924
2023		0.057	0.054	1.063
2024		0.042	0.050	0.839
Mean		0.046	0.055	0.867

3.1.1 Initial emergence of weak decoupling during the "11th five-year plan" period

During the "11th Five-Year Plan" period (2006–2010), the overall relationship between China's total energy consumption and economic growth was in a state of weak decoupling, with an average annual decoupling index (T value) of 0.575. The average annual growth rate of energy consumption remained lower than that of economic growth, indicating the initial improvement in China's energy utilization efficiency.

Three main factors contributed to this phenomenon. First, mandatory promotion of energy conservation and emission reduction policies. The Outline of the 11th Five-Year Plan for National Economic and Social Development of the People's Republic of China put forward the binding target of "reducing energy consumption per unit of GDP by 20%" for the first time, outdated production capacity in industries such as iron and steel and cement was gradually phased out nationwide, driving a 19% reduction in energy consumption per unit of GDP and providing core support for the weak decoupling. Second, rapid economic growth and industrial structure transformation. During the "11th Five-Year Plan" period, China's economy achieved an average annual growth rate of 11.3%. Meanwhile, the proportion of the secondary industry gradually decreased, while that of the tertiary industry continued to rise. The expansion of low-energy-consuming service industries reduced the overall energy consumption intensity, resulting in the growth rate of energy consumption lagging behind that of the economy. Additionally, the suspension of production in some industrial enterprises further suppressed energy demand. Third, preliminary penetration of technological progress. Energy-saving technologies are gradually being promoted in the industrial sector, the energy efficiency of industries such as thermal power generation and iron and steel was improved, indirectly slowing down the growth rate of energy consumption and strengthened the trend of weak decoupling.

3.1.2 Strengthened weak decoupling during the "12th five-year plan" period

During the "12th Five-Year Plan" period (2011–2015), the weak decoupling state between total energy consumption and economic growth was further deepened, with the average annual T value dropping to 0.459, 20.1% lower than that of the "11th Five-Year Plan" period. The gap between energy consumption growth and economic growth continues to widen, indicating significant achievements in energy efficiency improvement. Annual data show that the T value decreased steadily from 0.770 in 2011 to 0.193 in 2015, reflecting a stable strengthening of the decoupling trend. The year 2015 became a key turning point: the energy consumption growth rate was only 0.013, the lowest in this period, while the economy still maintained a growth rate of 0.070, pushing the decoupling index to a historical low.

The main influencing factors are as follows. First, supply-side structural reform. In 2013, China implemented the "Ten Measures for Air Pollution Prevention and Control." A large number of small coal-fired boilers were eliminated in the Beijing-Tianjin-Hebei region, the share of coal consumption has decreased. China proposed in 2015 that "three reductions, one reduction, one supplement" (cutting overcapacity, destocking, deleveraging, reducing costs, and strengthening weak links) policy. Industries such as coal and iron and steel took the lead in reducing overcapacity, which significantly lowered the growth rate of total energy consumption and directly drove the T value down to 0.193. Meanwhile, the declining proportion of high-energy-consuming industries further weakened the correlation between energy consumption and economic growth. Second, initiation of clean energy structure adjustment. During the "12th Five-Year Plan" period, the consumption share of clean energy such as natural gas, wind power, and photovoltaic power continued to rise, replacing part of traditional fossil energy and reducing the growth rate of total energy consumption, which contributed to the strengthening of weak decoupling. Third, economic growth shift and intensified energy efficiency policies. The economic growth rate dropped from 11.3% in the "11th Five-Year Plan" period to 7.9%. However, the Outline of the 12th Five-Year Plan for National Economic and Social Development of the People's Republic of China raised the target of reducing energy consumption per unit of GDP to 16%. Energy use efficiency continues to improve, while the growth rate of energy consumption and the economic growth rate both decline.

3.1.3 Weak decoupling fluctuations caused by the pandemic during the "13th five-year plan" period

During the "13th Five-Year Plan" period (2016–2020), the overall relationship between total energy consumption and economic growth remained weak decoupling, with an average annual T value of 0.549, weaker than that of the "12th Five-Year Plan" period. However, in 2020, due to the COVID-19 pandemic, the T value rose to 0.966, and the growth rate of energy consumption was basically the same as that of economic growth, shifting the decoupling state to growth coupling. If data from 2020 are excluded, the average annual T value of this period drops to 0.445, indicating that the weak decoupling trend actually continued to strengthen. The main reasons are as follows. First, Since 2017, large-scale clean heating transformation has been promoted in northern China, which pushed up electricity and natural gas consumption in the short term. In 2017, the growth rate of energy consumption doubled compared with 2016, leading to an increase in the T value from 0.250 to 0.471. This temporarily weakened the weak decoupling but did not change the overall trend. Second, during the 2020 pandemic, industrial production was significantly impacted. However, demands such as residential electricity use and the production of anti-epidemic materials supported energy consumption, making the growth rate of energy consumption almost equal to that of economic growth and forming a growth coupling state.

3.1.4 Dominance of growth coupling during the “14th five-year plan” period

In the first 4 years of the “14th Five-Year Plan” period (2021–2024), the decoupling state between total energy consumption and economic growth was generally shifted to growth coupling, with an average annual T value of 0.867. Except for 2021, which showed weak decoupling, the T values from 2022 to 2024 were all above 0.8. In 2023, the T value reached 1.063, the highest in the “14th Five-Year Plan” period, indicating an enhanced correlation between energy consumption and economic growth.

The main influencing factors are as follows. First, the rapid economic recovery after the pandemic and the resumption of residents’ travel, which have a high dependence on energy, have driven up the growth rate of total energy consumption. Second, geopolitical conflicts pushing up energy prices. The Ukraine crisis triggered a surge in global energy prices, and energy security was elevated to a new height in the national strategy, forcing China to increase production to ensure supply. In 2022, raw coal output increased by 10.5%, and coal imports grew significantly in 2023. The demand for coal for power generation and industrial use was fully met, becoming the core driver of the rising growth rate of total energy consumption and weakening the decoupling trend. Third, the impact of the “dual carbon” goals. China has seen an increase in the growth rate and proportion of consumption of clean energy such as natural gas, wind power, and solar energy. Among them, the installed capacity of photovoltaic power became the world’s largest in 2023. The growth rates of energy consumption and economic growth basically showed a synchronous growth trend, eventually forming a growth coupling state (Figure 3).

In summary, from 2006 to 2024, the decoupling state between China’s total energy consumption and economic growth shifted from weak decoupling to growth coupling. During the “11th Five-Year Plan” to “12th Five-Year Plan” periods, improvements in energy efficiency and structural transformation drove the continuous deepening of weak decoupling. Although the “13th Five-Year Plan” period was impacted by the short-term pandemic, however, the overall trend of weak decoupling has not changed. During the “14th Five-Year Plan” period, due to the economic recovery model and the pressure of ensuring energy supply, the decoupling state between energy consumption and economic growth shifted from weak decoupling to growth coupling.

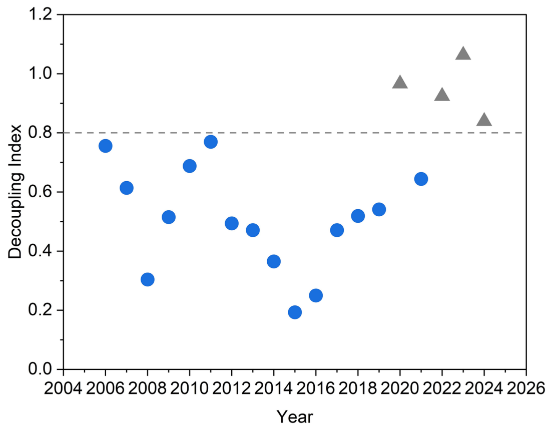

FIGURE 3
Decoupling states between china’s energy consumption and economic growth in different periods.

3.1.5 The “15th five-year plan” period will return to the track of weak decoupling

In accordance with the arrangements of the 20th National Congress of the Communist Party of China and the requirements of multiple development plans, such as the Outline of the Long-Range Goals for 2035, China needs to ensure an average annual economic growth rate of no less than 4.5% during the “15th Five-Year Plan” period to achieve the long-term goal of doubling the total economic output by 2035. The development of the energy sector will generally follow an accelerated process of clean and low-carbon energy transition (Shi et al., 2025). After non-fossil energy completes incremental substitution, it will gradually begin replacing existing fossil energy.

Based on “Outlook on the Development Environment of zhe Domestic and Foreign Oil and Gas Industries during the 15th Five-Year Plan Period” released by China National Petroleum Corporation (CNPC) and “Medium and Long-Term Outlook on the Industry Development Environment” by the Energy Economics Research Institute of CNOOC Group, the average annual growth rate of China’s primary energy consumption during the “15th Five-Year Plan” period will decrease significantly compared with that of the “14th Five-Year Plan” period, with an estimated average annual growth rate of approximately 2.3%. The demand for oil and coal will gradually peak, thereby driving the peak of fossil energy consumption, while non-fossil energy will maintain rapid development momentum.

Calculations based on Formula 1 show that during the “15th Five-Year Plan” period, China’s average annual economic growth rate will be much higher than the growth rate of energy consumption, and the relationship between total energy consumption and economic growth will return to the track of weak decoupling, providing support for the realization of the “dual carbon” goals and high-quality development. In the future, as non-fossil energy establishes its dominant position, the stability of decoupling is expected to achieve a higher level of stability in the new correlation model.

3.2 Decoupling state between traditional fossil energy consumption and economic growth

As the main component of China's energy consumption, the decoupling characteristics of traditional fossil energy from economic development are directly related to the realization of the "dual carbon" goals and the quality of economic transformation. From the perspective of consumption of traditional fossil energy, such as coal, oil, and natural gas, the growth rate of China's energy consumption gradually slowed during the "11th Five-Year Plan" to "13th Five-Year Plan" periods, with the average annual growth rate decreasing from 6.2 to 1.9%. Meanwhile, the economic growth trend was synchronized with the energy consumption growth trend, also slowing, but the economic growth rate remained relatively higher than that of energy consumption. The relationship between energy consumption and economic growth was in a state of weak decoupling, with the T value gradually decreasing from an average annual 0.531 in the "11th Five-Year Plan" period to 0.368 in the "13th Five-Year Plan" period. This gradual strengthening of the weak decoupling trend reflects the achievements in energy efficiency improvement and structural adjustment. However, this trend changed after the outbreak of the COVID-19 pandemic in 2020. Although the overall relationship between China's fossil energy consumption and economic growth remained weak decoupling during the "14th Five-Year Plan" period, the decoupling state fluctuated due to factors such as post-pandemic economic recovery and energy supply guarantee, and entered a state of growth coupling in 2023, indicating the fragility of the decoupling process (see Table 3). A detailed analysis is as below.

3.2.1 Dominance of weak decoupling in the "11th five-year plan" period, with natural gas showing growth negative decoupling

During the "11th Five-Year Plan" period, the overall relationship between China's traditional fossil energy consumption and economic growth was in a state of weak decoupling, with an average annual decoupling index (T value) of 0.531 (see Table 3). The average annual energy consumption growth rate of 6.2% was lower than the 11.3% average annual economic growth rate, reflecting the initial improvement in energy utilization efficiency during this period.

From the perspective of energy types, Coal and oil consumption show a weak decoupling from economic growth. While coal remains the mainstay of energy consumption, coal consumption intensity per unit of GDP has decreased, energy efficiency in the transportation sector has improved, and the growth rate of oil consumption is lower than that of economic growth. Natural gas showed growth negative

TABLE 3 Fossil energy consumption, economic growth elasticity coefficient, and decoupling index.

Year	△E				△G				T			
	Fossil Energy	Coal	Oil	Natural Gas	Fossil Energy	Coal	Oil	Natural Gas	Fossil Energy	Coal	Oil	Natural Gas
2006	0.096	0.096	0.078	0.233	0.127	0.127	0.127	0.127	0.756	0.756	0.611	1.835
2007	0.086	0.089	0.056	0.208	0.142	0.142	0.142	0.142	0.606	0.625	0.395	1.465
2008	0.019	0.015	0.011	0.167	0.097	0.097	0.097	0.097	0.200	0.157	0.116	1.719
2009	0.047	0.050	0.030	0.079	0.094	0.094	0.094	0.094	0.503	0.530	0.314	0.843
2010	0.062	0.037	0.138	0.226	0.106	0.106	0.106	0.106	0.589	0.349	1.305	2.134
Mean	0.062	0.057	0.063	0.183	0.113	0.113	0.113	0.113	0.531	0.483	0.548	1.599
2011	0.085	0.089	0.036	0.234	0.095	0.095	0.095	0.095	0.895	0.934	0.381	2.465
2012	0.024	0.014	0.051	0.084	0.079	0.079	0.079	0.079	0.307	0.175	0.650	1.066
2013	0.031	0.020	0.043	0.145	0.078	0.078	0.078	0.078	0.397	0.258	0.549	1.856
2014	0.015	0.003	0.039	0.086	0.075	0.075	0.075	0.075	0.197	0.040	0.525	1.141
2015	0.005	−0.017	0.078	0.050	0.070	0.070	0.070	0.070	0.078	−0.247	1.113	0.710
Mean	0.032	0.022	0.050	0.120	0.079	0.079	0.079	0.079	0.375	0.232	0.644	1.447
2016	0.005	−0.009	0.034	0.070	0.068	0.068	0.068	0.068	0.080	−0.125	0.494	1.024
2017	0.025	0.006	0.044	0.168	0.069	0.069	0.069	0.069	0.367	0.086	0.631	2.433
2018	0.025	0.008	0.035	0.140	0.068	0.068	0.068	0.068	0.361	0.117	0.519	2.064
2019	0.023	0.010	0.038	0.087	0.061	0.061	0.061	0.061	0.382	0.167	0.630	1.432
2020	0.015	0.008	0.011	0.073	0.023	0.023	0.023	0.023	0.651	0.349	0.498	3.188
Mean	0.019	0.005	0.032	0.108	0.058	0.058	0.058	0.058	0.368	0.119	0.554	2.028
2021	0.045	0.037	0.044	0.106	0.086	0.086	0.086	0.086	0.527	0.428	0.513	1.228
2022	0.018	0.030	−0.005	−0.018	0.031	0.031	0.031	0.031	0.565	0.983	−0.147	−0.584
2023	0.054	0.044	0.075	0.070	0.054	0.054	0.054	0.054	0.991	0.818	1.389	1.296
2024	0.016	0.017	−0.012	0.073	0.050	0.050	0.050	0.050	0.327	0.340	−0.240	1.460
Mean	0.033	0.032	0.026	0.058	0.055	0.055	0.055	0.055	0.603	0.642	0.379	0.850

decoupling, with an average annual T value of 1.599 (far greater than 1). The 18.3% average annual growth rate of natural gas consumption during this period was significantly faster than the economic growth rate, which reflected that in the early stage of energy structure cleaning, natural gas, as a relatively low-carbon fossil energy, experienced rapid expansion in demand driven by policy guidance and industrial substitution needs.

From the perspective of typical years, obvious changes occurred in 2010. Although fossil energy as a whole still showed weak decoupling (with a T value of 0.589), oil and natural gas displayed distinct trends: oil was in growth negative decoupling with a T value of 1.305, and natural gas was in strong growth negative decoupling with a T value of 2.134. This was closely related to the industrial rebound following the 2009 economic stimulus policy. The expansion of industries such as heavy industry and chemical industry drove a surge in the demand for oil and natural gas in 2010.

3.2.2 Decline in decoupling index and differentiation caused by structural adjustment in the "12th five-year plan" period

During the "12th Five-Year Plan" period, the weak decoupling trend between traditional fossil energy and economic growth was further strengthened, with the average annual T value dropping to 0.375 (a 29.4% decrease compared with the "11th Five-Year Plan" period), indicating remarkable achievements in energy efficiency improvement.

From the perspective of energy types, coal had an average annual T value of 0.232, showing clear weak decoupling characteristics, and even reached strong decoupling in 2015 (with a T value of −0.247). Oil had an average annual T value of 0.644, remaining in weak decoupling, but shifted to growth coupling in 2015 (with a T value of 1.113), with the energy consumption growth rate roughly matching the economic growth rate. Natural gas continued to show growth negative decoupling but with increased fluctuations, temporarily shifting to growth coupling in 2012 and 2014, this reflects that natural gas demand is more sensitive to fluctuations in economic cycles.

From the perspective of typical years, 2015 saw obvious structural changes and became a typical year for the differentiation of decoupling states in the "12th Five-Year Plan" period. Restricting new capacity in high-energy-consuming industries directly leads to a decline in coal consumption. The growth in oil consumption, however, was affected by the sharp drop in international oil prices. China's oil imports increased significantly, with the growth rate of oil consumption reaching 7.8%, slightly exceeding the economic growth rate.

3.2.3 Stable decoupling trend and short-term fluctuations caused by the pandemic in the "13th five-year plan" period

During the "13th Five-Year Plan" period, the weak decoupling state between traditional fossil energy and economic growth tended to be stable, with an average annual T value of 0.368 (basically the same as that in the "12th Five-Year Plan" period). During this period, the average annual growth rate of energy consumption dropped to 1.9%, and although the economic growth rate slowed down to 5.8% simultaneously, the "growth rate gap" remained stable, energy efficiency improvement entered a platform period.

From the perspective of energy types, coal had an average annual T value of 0.119, generally in a state of weak decoupling, and even achieved strong decoupling in 2016. This was due to the continuous advancement of the "overcapacity reduction" policy implemented in 2015. Oil had an average annual T value of 0.554, maintaining a stable weak decoupling state. The growth in demand primarily stemmed from the increase in private car ownership and the expansion of the logistics industry, although the initial rollout of new energy vehicles somewhat suppressed the rate of growth in oil consumption. Natural gas saw a strengthened growth negative decoupling characteristic, with an average annual T value of 2.028 and a high T value of 3.188 in 2020. This was related to the surge in natural gas demand driven by the clean heating transformation in northern China in winter during the "13th Five-Year Plan" period. In 2020, the proportion of natural gas consumption rose to 8.4%, an increase of 2.3 percentage points compared with 2015.

From the perspective of typical years, the short-term impact of the COVID-19 pandemic in 2020 disrupted the decoupling rhythm. In 2020, the economic growth rate dropped to 2.3% (the lowest since the reform and opening up), while the T value of fossil energy rose to 0.651, weakening the decoupling state. Among them, the T value of natural gas reached 3.188, mainly because the rigid demand for energy such as residential gas-fired power generation and heating increased during the pandemic, while the recovery of industrial demand lagged behind, leading to the "asynchrony" between energy consumption and economic growth.

3.2.4 Fluctuations in decoupling state and emergence of growth coupling in 2023 during the "14th five-year plan" period

From 2021 to 2024, the overall relationship between China's traditional fossil energy and economic growth remained weak decoupling, with an average annual T value of 0.603, though fluctuations increased significantly. In 2023, growth coupling emerged with a T value of 0.991, where the growth rate of energy consumption was nearly the same as that of economic growth.

From the perspective of energy types, coal had an average annual T value of 0.642, with weakened weak decoupling characteristics, and growth coupling occurred consecutively in 2022–2023, reflecting the rebound in coal consumption under the pressure of energy supply guarantee. Oil saw the largest fluctuations: it showed strong decoupling in 2022 (with a T value of −0.147), growth negative decoupling in 2023, and strong decoupling again in 2024. This was related to the interplay between the retaliatory rebound in travel demand after the pandemic and the accelerated substitution of new energy. Natural gas had an average annual T value of 0.850, shifting to growth coupling. It briefly achieved strong decoupling in 2022 but returned to growth negative decoupling in 2023–2024, reflecting the "transitional energy" attribute of natural gas in the energy transition, it is driven by cleaning policies while being affected by fluctuations in international gas prices.

From the perspective of typical years, 2023 was a key node for the reversal of the decoupling state in the "14th Five-Year Plan" period, where fossil energy consumption and economic growth entered a state of growth coupling. This was mainly driven by two factors. First, the economic recovery following adjustments to epidemic prevention and control measures drove the year-on-year demand for oil and coal up by 7.5 and 4.4%, respectively. Second, to cope with fluctuations in international energy prices and the impact of extreme weather, the coal industry made every effort to increase production to ensure supply. Data from China's National Bureau of Statistics shows that

China's coal imports reached 470 million tons in 2023, an increase of 61.8% compared with 2022, directly pushing up the growth rate of coal consumption.

Based on the comprehensive analysis above, three main conclusions can be drawn. First, the decoupling state between China's traditional fossil energy consumption and economic growth presents distinct periodic characteristics. During the "11th Five-Year Plan" to "13th Five-Year Plan" periods, the weak decoupling trend was gradually strengthened, reflecting the achievements in energy efficiency improvement and structural adjustment. Since the "14th Five-Year Plan" period, affected by factors such as post-pandemic economic recovery and energy supply guarantees, the decoupling state has fluctuated, even entering a state of growth coupling in 2023, indicating the fragility of the decoupling process.

Second, during the "11th Five-Year Plan" to "14th Five-Year Plan" periods, coal and oil consumption maintained a weak decoupling relationship with economic growth. With improvement in energy efficiency, energy consumption intensity has decreased, and the growth rate of energy consumption has remained lower than that of economic growth. From the perspective of the decoupling index, coal and oil have generally been in a state of weak decoupling, with only occasional deviations from this trend in individual years.

Third, the relationship between natural gas consumption and economic growth has long been in a state of growth negative decoupling. Rahman et al. (2020) argue that natural gas has a positive and significant effect on GDP growth in the long-run. Jin and Zhang (2025), Li et al. (2024), and Guangyue et al. (2023) argue that against the background of global warming, natural gas, as a clean and efficient fossil energy source and an important industrial raw material, has seen increased consumption driven by the combined effects of emission reduction policies, economic development, industrial demand, and urbanization, play a "bridge" role in the energy transition. As a result, during the four planning periods, the relationship between natural gas consumption and economic growth in China was characterized by either growth negative decoupling or growth coupling (see Figure 4).

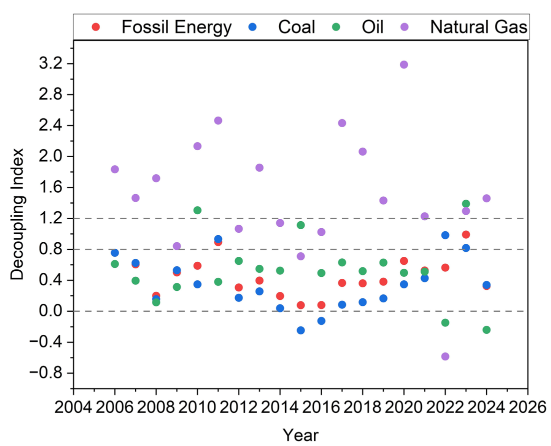

FIGURE 4
Decoupling indices between china's traditional fossil energy and economic growth.

3.2.5 Shift toward a strong decoupling trend during the "15th five-year plan" period

Zhixiong et al. (2025) studied the relationship between economic growth and carbon emissions in China's county-level cities, predicting that the decoupling will shift from weak decoupling to strong decoupling. During the "15th Five-Year Plan" period, the growth rate of fossil energy consumption in China is expected to slow down, with annual consumption growth rates of coal and oil entering negative territory. The relationship between fossil energy consumption and economic growth may shift towards a trend of strong decoupling. In terms of coal: The China National Coal Association predicts that China's total coal consumption will enter a peak plateau during the "15th Five-Year Plan" period. It is expected to gradually decrease after peaking around 2028, with an average annual growth rate turning negative. In terms of oil and gas: China National Offshore Oil Corporation(CNOOC)anticipates that China's total oil demand will enter a peak plateau during the "15th Five-Year Plan" period and show a gradual decline trend, dropping from 770 million tons in 2025 to 720 million tons in 2030,with an average annual decline of 1.3% during the "15th Five-Year Plan" period. China's natural gas supply and demand are expected to remain generally balanced, with consumption maintaining steady growth. CNOOC projected to reach 565 billion cubic meters by 2030, representing an average annual growth rate of approximately 5.1%. Calculations based on Formula 1 show that during the "15th Five-Year Plan" period, coal and oil will shift from weak decoupling to strong decoupling, while natural gas will continue to maintain a state of growth coupling.

3.3 Decoupling state between non-fossil energy consumption and economic growth

Calculation results show that since 2006, the relationship between China's non-fossil energy consumption and economic development has shifted from a growth coupling state in the "11th Five-Year Plan" period to a growth negative decoupling state. Since the "12th Five-Year Plan" period, the decoupling index has remained above 1.2 and shown a gradual upward trend, indicating that the dependence of economic development on non-fossil energy has been continuously increasing (see Table 4). As a core component of energy structure transformation, the decoupling relationship between non-fossil energy consumption and economic growth directly reflects the coordination between China's clean energy substitution process and economic development model. A detailed analysis is as below.

3.3.1 Transition from weak decoupling to growth negative decoupling in the "11th five-year plan" period

During the "11th Five-Year Plan" period, the overall decoupling state between non-fossil energy consumption and economic growth was growth coupling, with an average annual decoupling index (T value) of 1.092, but it showed obvious phased changes (see Table 4). From 2006 to 2007, the state was weak decoupling— the growth rate of non-fossil energy consumption was lower than that of economic growth, reflecting that economic development still relied mainly on fossil energy such as coal and oil, while non-fossil energy served only as a supplementary energy source. From 2008 to 2010, the state shifted

TABLE 4 Non-fossil energy consumption, economic growth elasticity coefficient, and decoupling index.

Year	Periods	△E	△G	T
2006	"11th Five-Year Plan" Period (2006–2010)	0.096	0.127	0.756
2007		0.102	0.142	0.717
2008		0.153	0.097	1.577
2009		0.061	0.094	0.648
2010		0.187	0.106	1.760
Mean		0.120	0.113	1.092
2011	"12th Five-Year Plan" Period (2011–2015)	−0.041	0.095	−0.431
2012		0.200	0.079	2.529
2013		0.090	0.078	1.156
2014		0.138	0.075	1.843
2015		0.076	0.070	1.090
Mean		0.093	0.079	1.237
2016	"13th Five-Year Plan" Period (2016–2020)	0.102	0.068	1.496
2017		0.080	0.069	1.161
2018		0.104	0.068	1.527
2019		0.090	0.061	1.475
2020		0.062	0.023	2.708
Mean		0.088	0.058	1.674
2021	"14th Five-Year Plan" Period (2021–2024)	0.108	0.086	1.261
2022		0.084	0.031	2.712
2023		0.075	0.054	1.396
2024		0.068	0.050	1.360
Mean		0.084	0.055	1.682

to growth negative decoupling, where the growth rate of non-fossil energy consumption was significantly higher than that of economic growth. This transition was closely related to the increase in national investment in hydropower and wind power projects after the 2008 global financial crisis, as well as policy promotion during the sprint period for achieving the "11th Five-Year Plan" energy conservation and emission reduction targets in 2010. From a data perspective, the average annual growth rate of non-fossil energy consumption during the "11th Five-Year Plan" period was 0.120, slightly higher than the 0.113 average annual economic growth rate. This indicates that the proportion of non-fossil energy in total energy consumption began to increase slowly, but fossil energy still dominated.

3.3.2 Establishment of the dominant position of growth negative decoupling amid fluctuations in the "12th five-year plan" period

During the "12th Five-Year Plan" period, the decoupling state between non-fossil energy consumption and economic growth fluctuated, but overall it shifted toward growth negative decoupling, with the average annual T value rising to 1.237. In 2011, the T value was −0.431, showing strong decoupling—mainly due to the delayed construction of some hydropower projects and technical bottlenecks in wind power grid connection that year, which led to a phased decline in non-fossil energy supply. From 2012 to 2014, the T values reached 2.529 and 1.843 respectively, indicating a state of strong growth negative decoupling. The growth rate of non-fossil energy consumption was far higher than that of economic growth, reflecting the prominent effects of clean energy policies in the mid-to-late "12th Five-Year Plan" period. In 2015, it briefly returned to growth coupling, primarily due to the slowdown in economic growth. However, the average annual growth rate of non-fossil energy consumption remained higher than the economic growth rate, indicating that its supporting role in economic growth began to emerge, and the energy structure transformation entered an acceleration period.

3.3.3 Continuous strengthening of growth negative decoupling in the "13th five-year plan" period

During the "13th Five-Year Plan" period, the growth negative decoupling state between non-fossil energy consumption and economic growth was further consolidated, with the average annual T value rising to 1.674, the highest among the four periods. Except for a brief period of growth coupling in 2017, all other years showed growth negative decoupling. Among them, the T value reached 2.708 in 2020, a historical peak, and the growth rate of non-fossil energy consumption was nearly three times that of economic growth. This was mainly due to the sharp decline in economic growth caused by the pandemic, while the rigid demand for residential electricity use continued to grow. Moreover, following the proposal of the "dual carbon" goals, the construction of non-fossil energy projects such as photovoltaic and wind power was accelerated, promoting the countercyclical expansion of non-fossil energy consumption. During the "13th Five-Year Plan" period, the gap between the average annual growth rate of non-fossil energy consumption and economic growth further widened, marking the initial establishment of its "leading position" in the new energy system.

3.3.4 Normalization of growth negative decoupling in the "14th five-year plan" period

In the first 4 years of the "14th Five-Year Plan" period, non-fossil energy consumption and economic growth continued to maintain a growth negative decoupling state, with an average annual T value of 1.682, basically the same as that in the "13th Five-Year Plan" period, and the decoupling trend tended to be stable. Following the proposal of the "dual carbon" goals in 2020, investment in renewable energy such as wind power and photovoltaic accelerated. From 2021 to 2023, the installed capacity of wind power and photovoltaic increased by more than 30% annually, driving the continuous growth negative decoupling from 2021 to 2024. The T value remained stable between 1.261 and 1.396, and the growth rate of non-fossil energy consumption consistently outpaced that of economic growth, indicating that the dependence of economic growth on clean renewable energy has become a normal state.

Based on the comprehensive analysis above, the decoupling state between China's non-fossil energy consumption and economic growth has exhibited the following characteristics: transitional features in the "11th Five-Year Plan" period, fluctuating growth in the "12th Five-Year Plan" period, accelerated penetration in the "13th Five-Year Plan" period, and stable dominance in the "14th Five-Year Plan" period. Essentially, this is the result of the combined effects of policy guidance, technological progress, and economic structure transformation. Overall, the evolution of the decoupling state between non-fossil energy consumption and economic growth reflects the achievements of China's energy structure transformation (Figure 5).

3.3.5 Sustained growth negative decoupling during the "15th five-year plan" period

With the deepening of the "dual carbon" goals and further breakthroughs in new energy technologies, China's energy transition is accelerating, and non-fossil energy is expected to maintain a rapid development momentum, accounting for approximately 80% of the increment in energy consumption, with an average annual growth rate of about 8.2%. The construction of a new power system and new power grids is advancing steadily, and the electrification level of end-use energy will be further improved. By 2030, China's electricity demand is projected to sustain a medium-to-high growth rate, with the electrification process entering the mid-transition stage and the electrification level of end-use energy rising to 35–36%. Calculations based on Formula 1 indicate that the growth negative decoupling state between non-fossil energy consumption and economic growth will persist. However, vigilance is required against potential disruptions to the decoupling trend caused by sharp economic fluctuations or technological breakthroughs.

3.4 Analysis of decoupling stability

As shown in Table 5, during the four Five-Year Plan periods, there were significant differences in the decoupling stability between China's energy consumption and economic growth, reflecting the dynamic changes in energy transition, policy regulation, and economic environment at different stages. During the "11th Five-Year Plan" period, the decoupling stability coefficient of energy consumption was 0.508, at a medium level. This indicates that the weak decoupling state between energy consumption and economic growth had initially taken shape, but it was not stable and was prone to being affected by internal and external factors. During the "12th Five-Year Plan" period, the decoupling stability coefficient dropped to 0.209, the lowest among the four periods, suggesting that the decoupling state was stable and less susceptible to disturbances from internal and external factors. During the "13th Five-Year Plan" period, the decoupling stability coefficient rose to 0.749, the highest among the four periods, indicating that the decoupling state had extremely strong continuity before the pandemic. However, the decoupling index surged to 0.966 in 2020; if this year is excluded, the stability coefficient actually drops to 0.407. Under the pandemic, industrial production was restricted, but the rigid demand for residential electricity consumption continued to grow. The mismatch between energy consumption and economic growth led to a short-term reversal of the decoupling state, and the impact of external disturbances on stability was significant. During the "14th Five-Year Plan" period, the decoupling stability coefficient was 0.212, close to that of the "12th Five-Year Plan" period, indicating a relatively high stability of the decoupling state—but under a state of growth coupling. This suggests that during this period, China's energy transition entered a critical stage of replacing old energy sources with new ones: fossil energy still played a key role in ensuring supply, while non-fossil energy, though growing rapidly, had not yet formed a stable substitution capacity. As a result, the growth rate of energy consumption is vulnerable to the impact of economic recovery and fluctuations in international energy prices, and the growth coupling state is characterized by both continuity and volatility. In the future, as non-fossil energy consolidates its dominant position, the decoupling stability is expected to adjust in line with the new decoupling state.

TABLE 5 Decoupling stability of china's energy consumption in different periods.

Periods	Stability coefficient
"11th Five-Year Plan" Period (2006–2010)	0.508
"12th Five-Year Plan" Period (2011–2015)	0.209
"13th Five-Year Plan" Period (2016–2020)	0.749
"14th Five-Year Plan" Period (2021–2024)	0.212

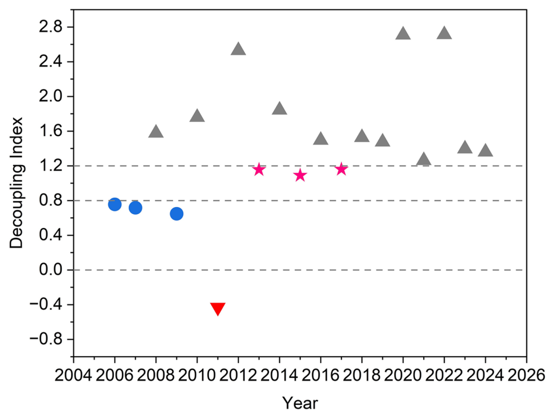

FIGURE 5
Decoupling states between china's non-fossil energy and economic growth in different periods.

3.5 Conclusion

By establishing the Tapio decoupling model for energy consumption and economic growth, this study analyzes the decoupling relationship between economic development and energy consumption in China during the periods from the "11th Five-Year Plan" to the "14th Five-Year Plan," and draws the following conclusions:

First, the decoupling state between China's total energy consumption and economic growth has shifted from weak decoupling to growth coupling. During the "11th Five-Year Plan" to "13th Five-Year Plan" periods, the overall relationship between the two was in a state of weak decoupling, the average value ranges from 0.459 to 0.575. With the transformation of the energy structure and the improvement of energy efficiency, the decoupling index of energy consumption continued to decline. During the "14th Five-Year Plan" period, the decoupling state shifted from weak decoupling to growth coupling. On the one hand, China's economic growth has moved toward high-quality development, with a slight slowdown in economic growth rate; on the other hand, the pace of energy transition has accelerated—the growth rate and proportion of consumption of clean energy such as natural gas, wind power, and solar energy have continued to increase, and the growth rates of energy consumption and economic growth have basically shown a synchronous growth trend. During the "15th Five-Year Plan" period, as the economic recovery model transforms toward "low energy consumption and high added value," with the continuous strengthening of clean energy substitution and breakthroughs in energy efficiency technologies, the relationship between total energy consumption and economic growth is expected to return to the track of weak decoupling, providing support for the realization of the "dual carbon" goals and high-quality development.

Second, there are significant differences in decoupling indices among fossil energy sources with different carbon emission levels. The consumption of coal and oil (with higher carbon emission levels) has generally maintained a weak decoupling relationship with economic growth, while the consumption of natural gas (with lower carbon emission levels) has long been in a state of growth negative decoupling from economic growth. With the deepening of the "dual carbon" goals and the substitution of renewable energy, during the "15th Five-Year Plan" period, the relationship between coal and oil consumption and economic growth may shift toward a strong decoupling trend. However, the decoupling index between natural gas and economic growth shows a downward trend, and weak decoupling may be achieved in the future.

Third, since the "12th Five-Year Plan" period, especially after 2018, China's economic growth has shown a high degree of dependence on non-fossil energy, and the decoupling relationship between the two has shifted from weak decoupling to growth negative decoupling, the average decoupling index during the "14th Five-Year Plan" period reached 1.682. This shift essentially is the result of the combined effects of policy guidance, technological progress, and economic structure transformation. During the "15th Five-Year Plan" period, non-fossil energy consumption will still play an important role in the process of energy transition and economic growth. With the rapid development of non-fossil energy and the further improvement of the electrification level of end-use energy, the substantial increase in non-fossil energy power generation will drive China's electricity demand to maintain medium-to-high growth, and the relationship between non-fossil energy consumption and economic growth will maintain a long-term state of growth negative decoupling.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Author contributions

HB: Conceptualization, Data curation, Project administration, Resources, Writing – original draft, Writing – review & editing. MW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2025.1728546/full#supplementary-material

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